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CORRELATION OF HEAT-TRANSFER DATA FOR THE APOLLO AFTERBODY AT MACH NUMBERS 8 TO 20

by George Lee

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CORRELATION OF HEAT-TRANSFER DATA FOR THE APOLLO AFTERBODY AT MACH NUMBERS 8 TO 20*

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SUMMARY

Heat-transfer data for the afterbody of the Apollo Command Module have been compared on the basis of Stanton number and Reynolds number. The data were for Mach numbers of 8 to 20, angles of attack of 0° and 33°, Reynolds numbers of 0.010×10^6 to 1.9×10^6, and total stream enthalpies of 300 to 4000 Btu/lb. The test streams were air and helium. Despite the wide range of test conditions, the data correlate and can be reasonably well represented by a straight line of the form $St \sim Re^{-1/2}$.

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AUTHOR

INTRODUCTION

Recently a large amount of afterbody heating and pressure data have been obtained for the Apollo Command Module from various facilities. The data were obtained for Mach numbers of 8 to 20, angles of attack of 0° and 33°, free-stream Reynolds numbers, based on model diameter, of 0.010×10^6 to 1.9×10^6, and total stream enthalpies of 300 to 4000 Btu/lb. The test gases were air and helium. Some of these data have been reported in references 1 and 2. Other data, obtained at the Ames Research Center, 1-Foot Hypervelocity Shock Tunnel at M = 10 (ref. 3), and arc-heated air facility (ref. 4) are unpublished. The purpose of this report is to compare and correlate the available data.

SYMBOLS

c_p	specific heat, Btu/lb °F
h	local heat-transfer coefficient, $\frac{q}{T_t - T_w}$, Btu/sec ft^2 °F
H_t	total stream enthalpy, Btu/lb
M	Mach number
p	pressure, lb/ft^2
q	heat flow, Btu/ft^2 sec
R	maximum cross-sectional radius of model, ft

Re Reynolds number, $\frac{\rho V x}{\mu}$

S surface distance measured from model axis of symmetry, ft

St Stanton number, $\frac{h}{c_p \rho V}$

T_t total temperature, deg

T_w wall temperature, deg

V local stream velocity, ft/sec

x surface distance measured from the stagnation point, ft

α angle of attack, deg

ρ local density, lb/ft^3

μ local viscosity, lb/sec ft

METHOD OF ANALYSIS

All of the data presented herein are in terms of the local Stanton and local Reynolds numbers which were calculated using measured stagnation and afterbody pressures and the assumption that the flow expanded isentropically from the stagnation point to the afterbody. With the further assumption that the gas was in equilibrium, the local Mach number, velocity, density, temperature, viscosity, and specific heat were calculated from the appropriate tables in references 5 to 9. The location of the stagnation point for $\alpha = 33^\circ$ was calculated by the method of reference 10. Although the calculated location varied somewhat depending on the enthalpy and test stream, a constant value, $S/R = 0.86$, was used for all cases.

RESULTS AND DISCUSSION

The data from a wide range of facilities and test conditions are presented in figures 1 and 2 along with the well-known theory for laminar flow on a flat plate. It is evident that the data correlate and can be reasonably well represented by a straight line of the form $St \sim Re^{-1/2}$. For 0° angle of attack, the Stanton numbers given by flat-plate theory are generally greater than those measured, particularly on the forward section of the afterbody. It is reasonable to conclude that the flow is separated since heat-transfer rates in separated flows are lower than those in attached flows. It is further evident that when the body is at an angle of attack of 33° so that the upper surface of the afterbody becomes alined with the free stream, the data are in quantitative agreement with laminar flat-plate theory.

CONCLUSIONS

1. Heat-transfer data for the Apollo afterbody can be correlated in terms of a Stanton and Reynolds number based on local stream properties.

2. When the afterbody is alined with the free-stream direction, the heat-transfer data along the most windward streamline agree very well with laminar flat-plate theory.

Ames Research Center
National Aeronautics and Space Administration
Moffett Field, Calif., Oct. 25, 1963

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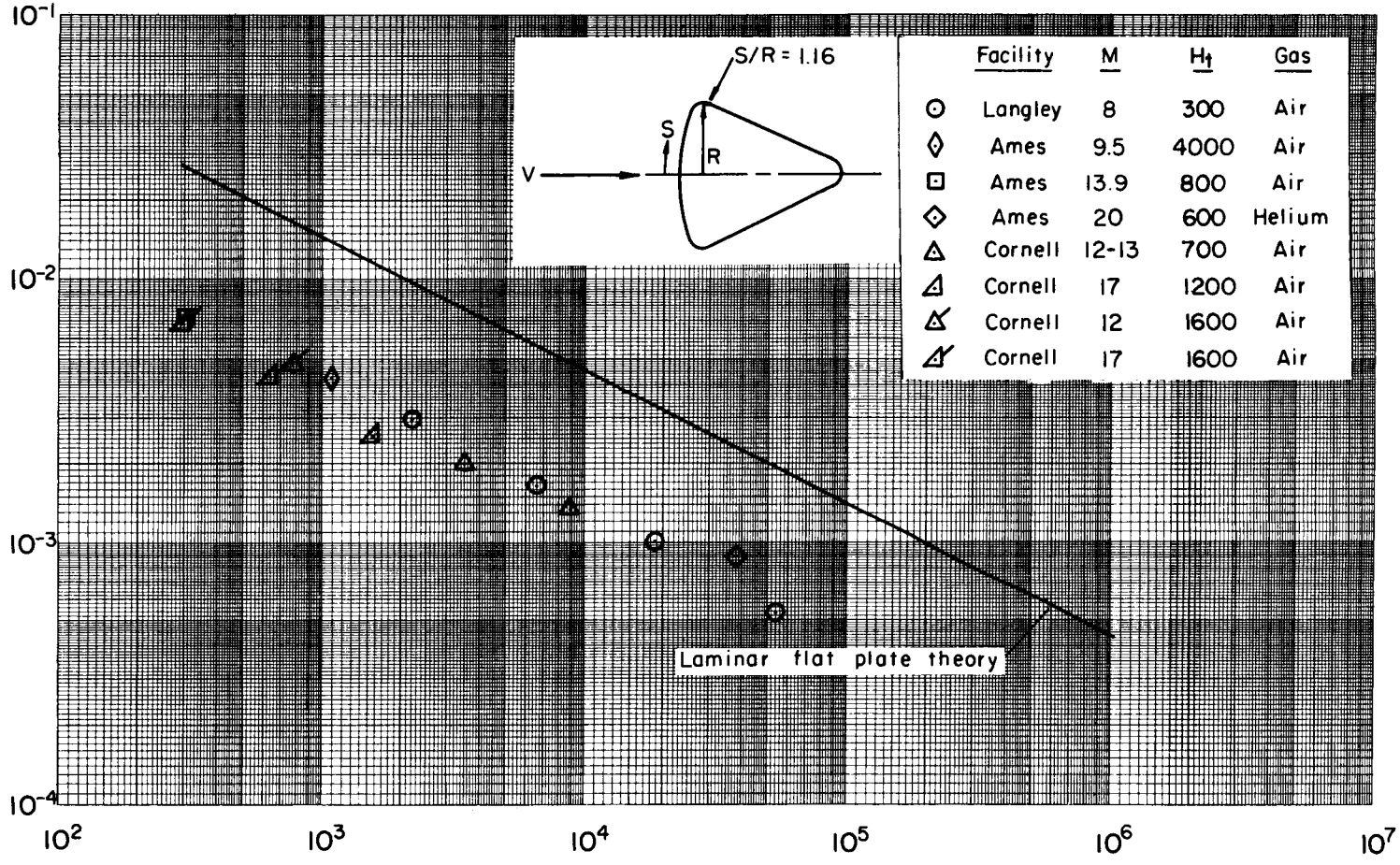
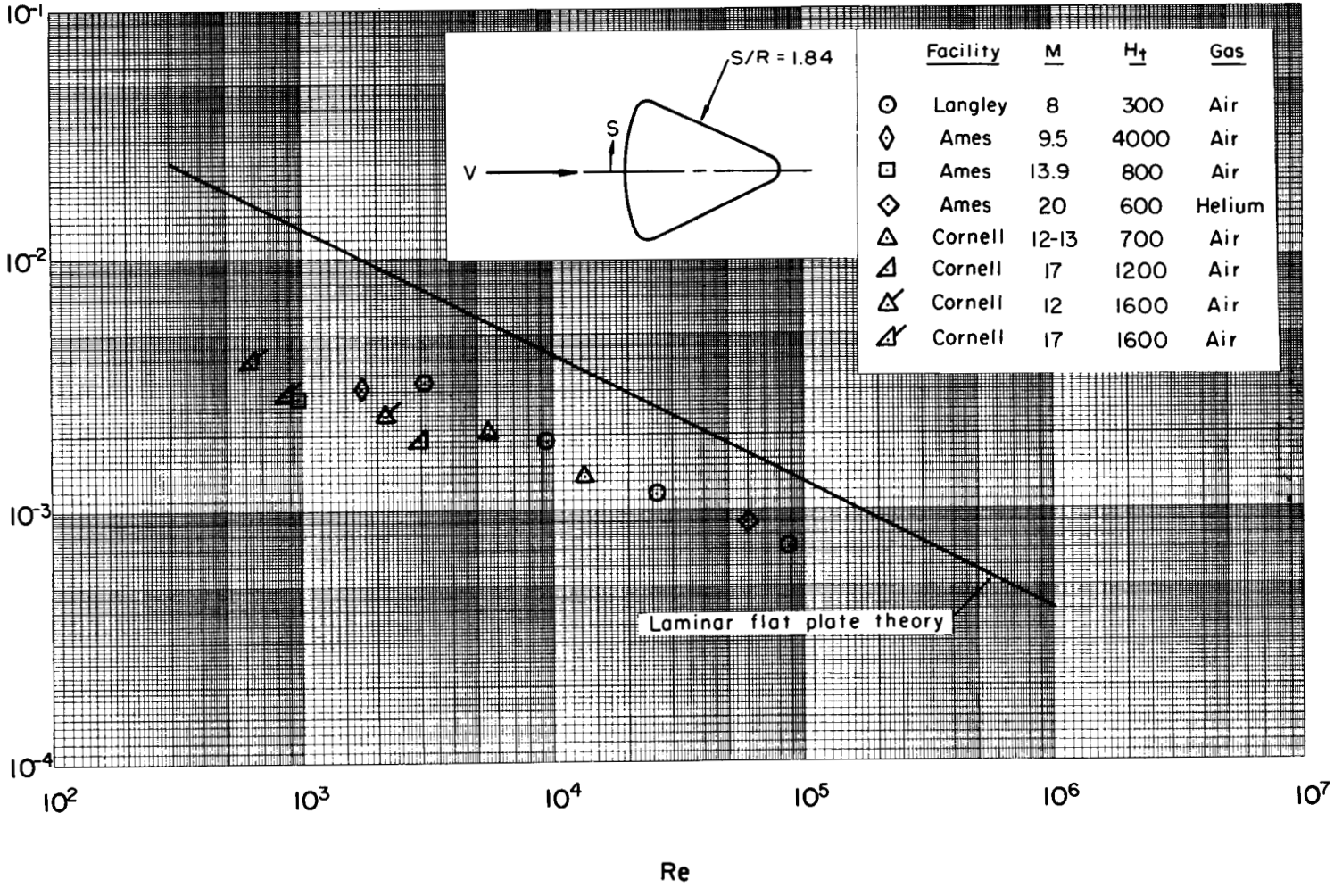


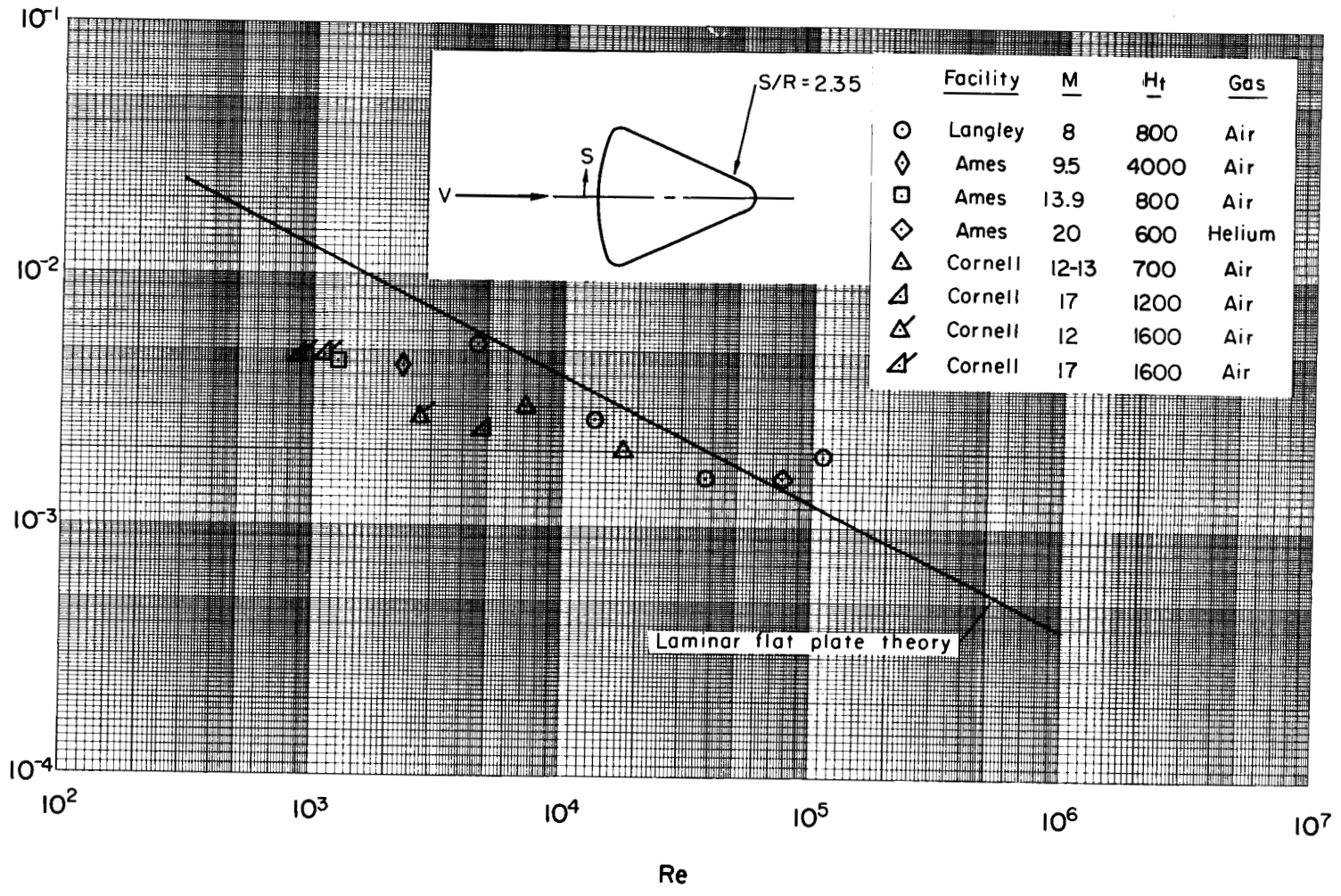
(a) S/R = 1.16

Figure 1.- Correlation of Apollo afterbody heat-transfer data at $\alpha = 0^{o}$.



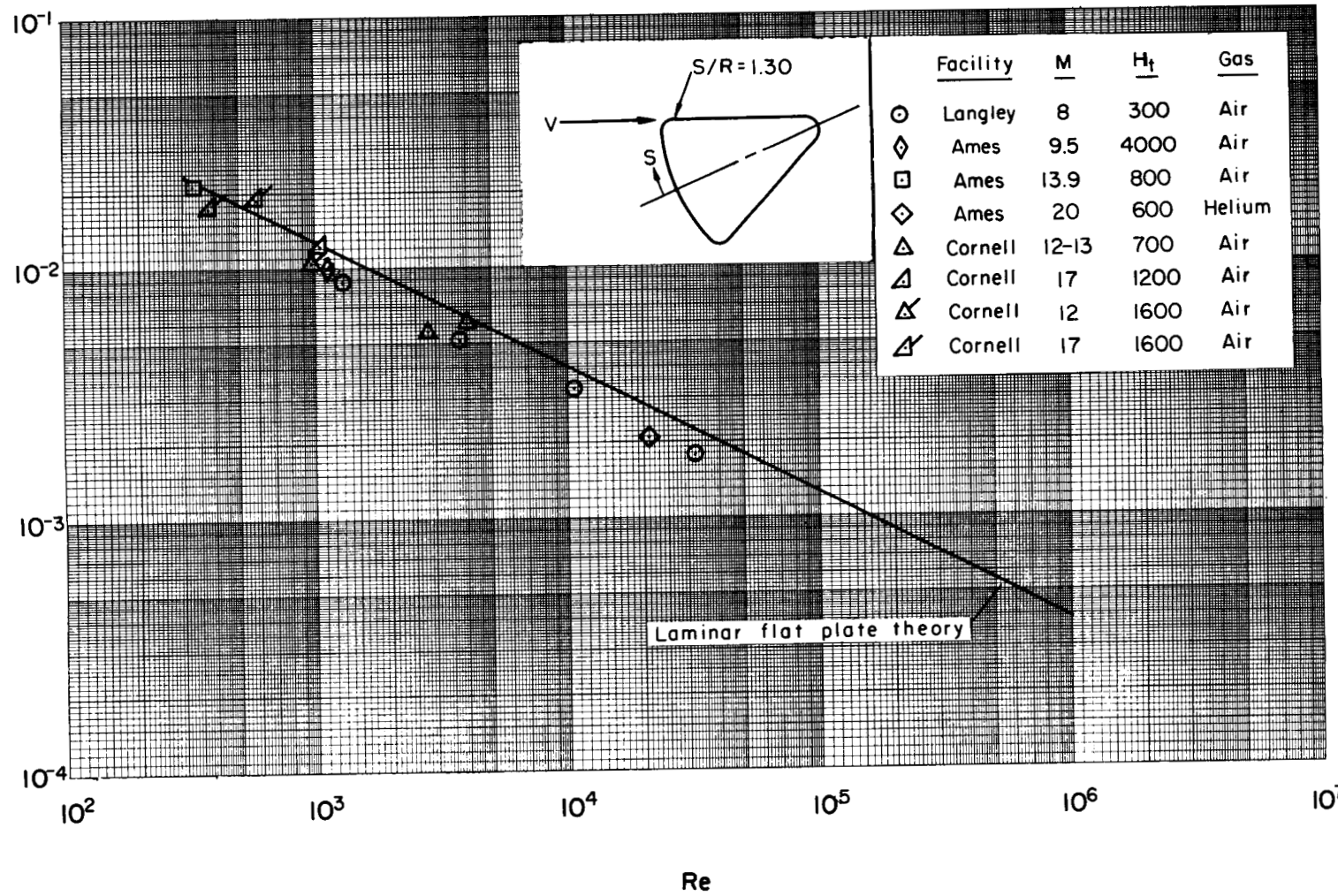
(b) S/R = 1.84

Figure 1.- Continued.



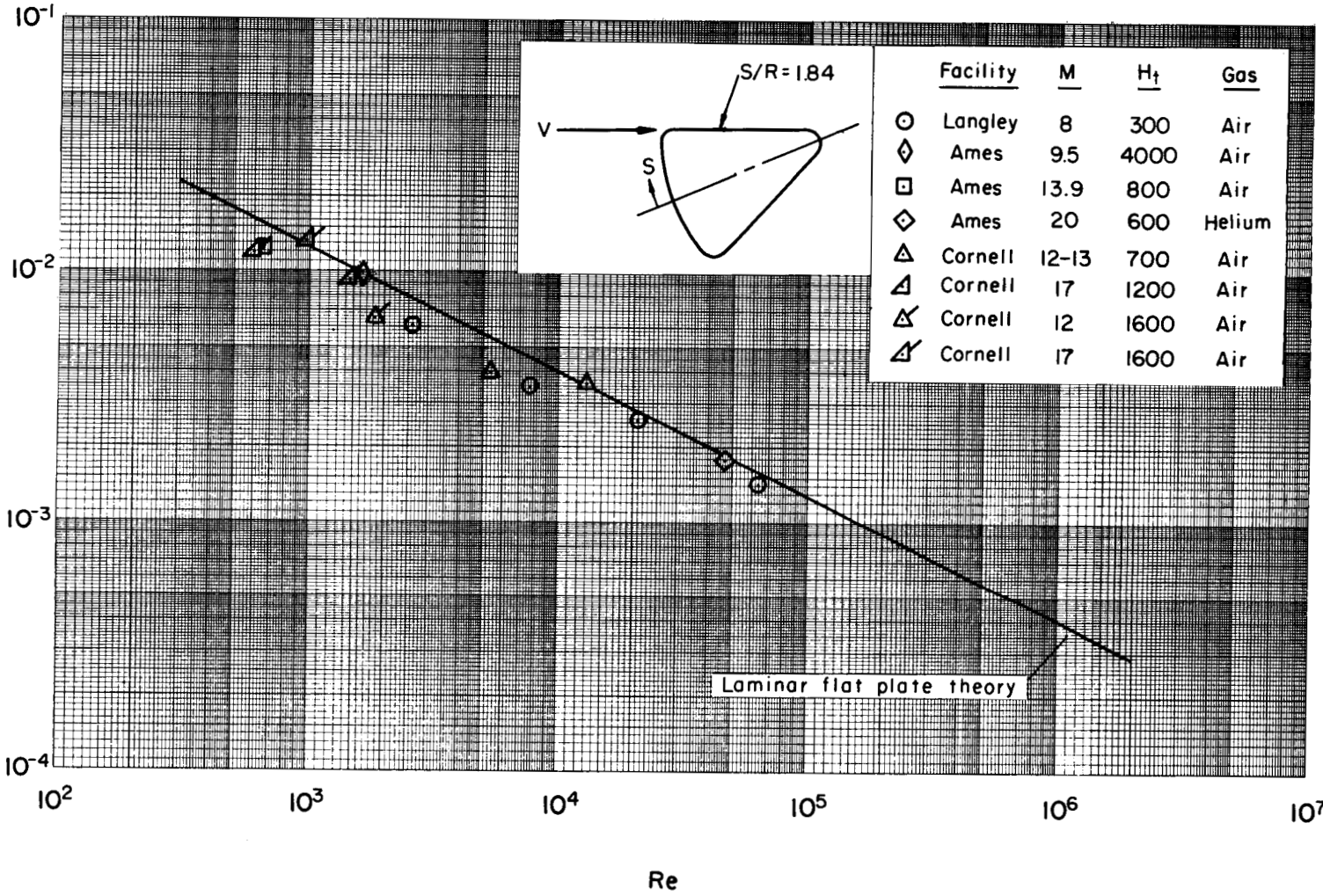
(c) S/R = 2.35

Figure 1.- Concluded.



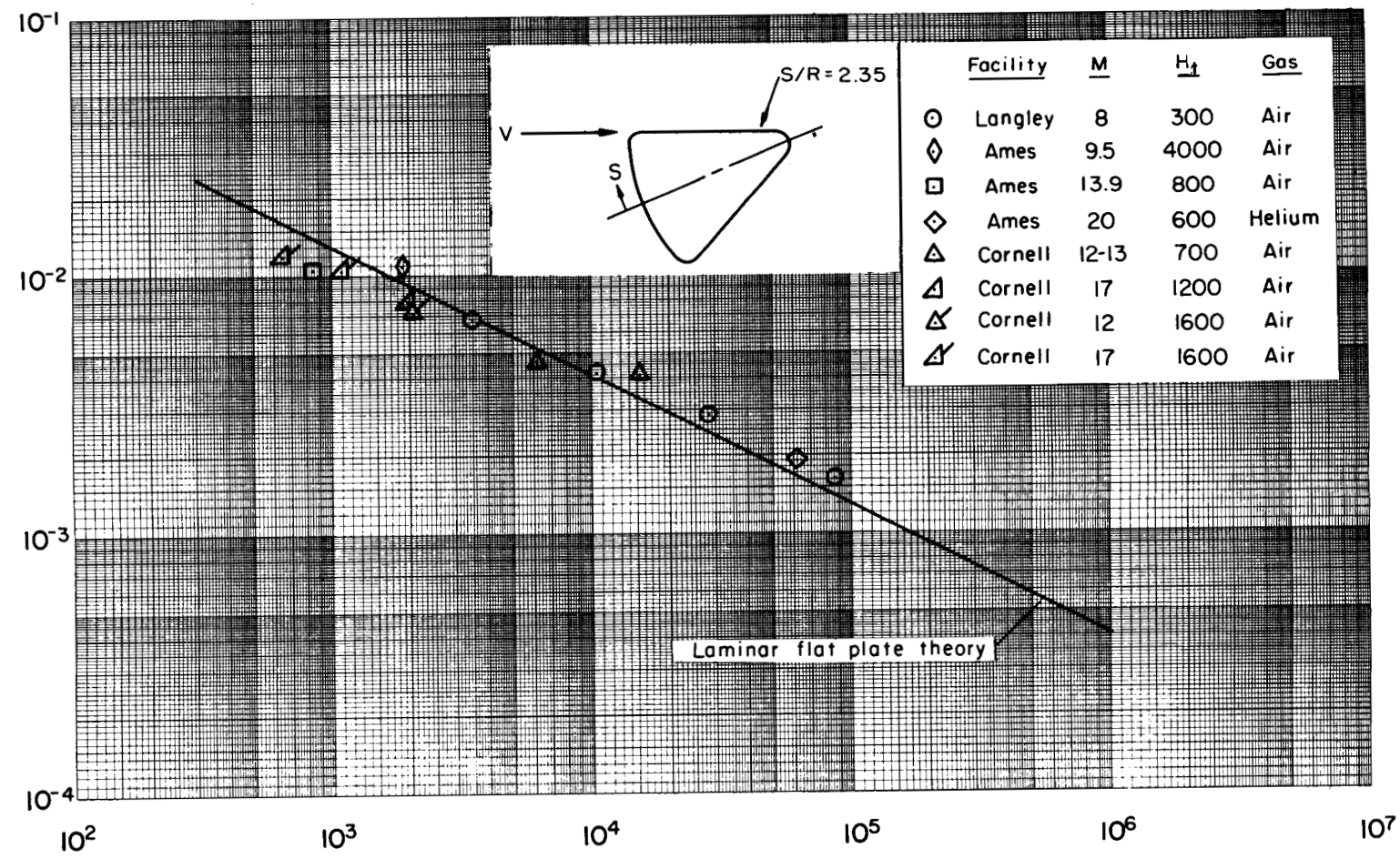
(a) S/R = 1.3

Figure 2.- Correlation of Apollo afterbody heat transfer at $\alpha = 33^{\circ}$.



(b) S/R = 1.84

Figure 2.- Continued.



(c) S/R = 2.35

Figure 2.- Concluded.